NCL 70-75R

EMBRITTLEMENT BY LIQUID METALS

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Final Report for the Period 9 March 1970 - 8 October 1970

Contract No. DAHC04-07-C-0028

November 1970

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EMBRITTLEMENT BY LIQUID METALS

During the period of this report, the earlier investigation[1] of the effects of second phases on the susceptibility of zinc-cadmium alloys to embrittlement by liquid mercury at ambient temperature was continued. The investigation with zinc-cadmium alloys is intended to elucidate the roll of cadmium as an environment insensitive (i.e., non-embrittling) second phase in inhibiting the embrittlement of the matrix phase (zinc) in mercury. Accordingly, a series of eight zinc-cadmium alloys containing 0 to 92 a/o cadmium were prepared* in sheet form. Standard tensile specimens (2 in. long and 1.5 mm thick) were stamped out from the sheet and were sealed under vacuum in pyrex tubes. The alloys were heat treated in the range 200° to 250°C for periods varying from 16 hours to 12 weeks. The extended heat treatment was required for obtaining large and uniform grain size for alloys containing high percentages of cadmium (~ 10 to 70 a/o cadmium). The tensile specimens (grain size ~ 0.5 mm) were tested in tension in air and mercury environments at 25°C using a strain rate of 0.005 in./min. It was found that the flow stress of zinc-cadmium alloys increased from ~ 2.0 Kg/mm^2 for pure zinc to ~ 8 Kg/mm^2 for 20 a/o cadmium and subsequently remained unchanged with further additions of cadmium. However, the fracture stress of these alloys in mercury increased with increased additions of cadmium. The alloys containing up to 10 a/o cadmium fractured below their flow stress, whereas alloys containing 10 a/o or more cadmium (~ 70%) fractured above the flow stress. Since fracture occurs prior to yielding, fracture in alloys containing up to 10 a/o cadmium is considered to be nucleation controlled. However, in accord with the original proposition,[2] for these alloys an academic inhibition of embrittlement has occurred. This is because small additions (~ 0.2 a/o) of cadmium to zinc

*These alloys were specially prepared by the Cominco Co., Portland, Oregon.

are known to decrease the fracture stress of zinc by some 70%[3] whereas in the present case fracture stress of zinc increases with increasing cadmium content. It is considered that crack blunting due to relaxation of stress concentrations caused by plastic deformation in the ductile cadmium phase which is present at the grain boundary may be responsible for this behavior. This possibility is being investigated at the present time. For alloys containing 10 to 50 a/o cadmium, fracture initiates after yielding. Metallographic examinations revealed the presence of blunted cracks which did not propagate to failure. Fracture in these alloys therefore may be considered to be propagation controlled. In this instance, in accord with the original proposition,[2] the ductile second phase has caused inhibition of embrittlement of zinc by liquid mercury. Detailed metallographic examinations are in progress.

In other studies, polycrystalline aluminum 2.5 w/o-zinc 5.3 w/o-magnesium alloys containing varying thicknesses (0.04 to 0.35 microns) of denuded zones at the grain boundary were tested in tension to fracture in liquid mercury at 25°C. The fracture data were intended to elucidate the effects of the variation in the thickness of the denuded zones on the susceptibility of aluminum alloys to embrittlement by liquid mercury. From the fracture data, however, no correlation could be established between the thickness of the denuded zones and severity of the embrittlement of these alloys in mercury environments.

In addition, studies were undertaken to investigate the roll of the chemical nature of the liquid metal or liquid metal solutions in determining the occurrence and the severity of liquid metal embrittlement in a given embrittlement couple. These studies revealed that the severity of liquid metal embrittlement is related to the electronegativities of the participating

solid and liquid metal. The results of these studies were prepared for publication in a paper entitled "The Occurrence of Liquid-Metal Embrittlement" and have since been accepted for publication in "Physica Status Solidi." An abstract of this paper is presented below.

Abstract: A study has been made of the fracture behavior of cadmium in liquid mercury and several liquid mercury solutions. It is shown that the degree of embrittlement induced in a solid metal can be significantly and predictably affected by incorporating selected embrittling elements in solution in the liquid-metal environment. For example, additions of more than 8 at. pct of indium to mercury at room temperature caused cadmium to behave in a brittle manner in this otherwise "inert" environment. Following consideration of the experimental data from such experiments, and also from the published literature, it is suggested that a correlation exists between the occurrence and severity of liquid-metal embrittlement and the electronegativities of the participating solid and liquid metals. It appears that maximum embrittlement occurs when the solid metal and the active liquid metal are of similar electronegativity, and that the severity of embrittlement decreases as the difference in electronegativity between the two metals increases.

During the period of this report, the Principal Investigator presented lectures on the subject "Brittle Fracture in Liquid Metal Environments" at UCLA and Stanford University. Recently, he has been invited to write a comprehensive review paper on the subject "Liquid Metal Embrittlement" for publication as a monograph for "Progress in Materials Science," Editor, Professor B. Chalmers.

Publications on the Contract During the Report Period

(1) "Crack Initiation in Zn-Hg Embrittlement Couple," Corrosion by Liquid Metals, Plenum Press, p. 449-459, 1970.

(2) "Occurrence of Liquid Metal Embrittlement," in press, Physica Status Solidi, 1970.

References

(1) M. H. Kamdar, Final Report to ARO(D), Contract No. DA-31-124-ARO(D)-63, December 1969.

(2) M. H. Kamdar, "Embrittlement by Liquid Metals," RIAS Proposal No. 291 to ARO(D), October 2, 1968.

(3) M. H. Kamdar and A. R. C. Westwood, Acta Met., 16, p. 1335 (1968).

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Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
Northrop Corporate Laboratories

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP
NA

3. REPORT TITLE
Embrittlement by Liquid Metals

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Final Report: 9 March 1970 - 8 October 1970

5. AUTHOR(S) *(First name, middle initial, last name)*
M. H. Kamdar

6. REPORT DATE
November 70

7a. TOTAL NO. OF PAGES
4p

7b. NO. OF REFS

8a. CONTRACT OR GRANT NO.
DAHC04 70 C 0028

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
NA

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
9218.1-MC

10. DISTRIBUTION STATEMENT
This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
U. S. Army Research Office-Durham
Box CM, Duke Station
Durham, North Carolina 27706

13. ABSTRACT

This report gives a summary of the investigations performed under the general title, "Embrittlement by Liquid Metals." During the period of this report, an earlier investigation of the effects of second phases on the susceptibility of zinc-cadmium alloys to embrittlement by liquid mercury at ambient temperature was continued. The investigation with zinc-cadmium alloys was intended to elucidate the roll of phase in inhibiting the embrittlement of the matrix phase (zinc) in mercury. In other studies, polycrystalline aluminum 2.5 w/o-zinc 5.3 w/O-magnesium alloys containing varying thicknesses (0.04 to 0.35 microns) of denuded zones at the grain boundary were tested in tension to fracture in liquid mercury at 25°C. In addition, studies were undertaken to investigate the roll of the chemical nature of the liquid metal or liquid metal solutions in determining the occurrence and the severity of liquid metal embrittlement in a given embrittlement couple. These studies revealed that the severity of liquid metal embrittlement is related to the electronegativities of the participating solid and liquid metal.

14. KEY WORDS
Liquid Metals
Metals - Embrittlement
Zinc-Cadmium Alloys
Polycrystalline Aluminum

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Unclassified